The APS Diagnostics Beamlines

A Status Report from Sector 35

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ANL/AOD/DIAG

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Mission Statement for Diagnostics Group

The mission of the Diagnostics Group is to design, implement, characterize, and maintain state-of-the-art particle and photon beam diagnostics for the APS accelerators and transport lines in order to support reliable, ultra-stable machine operation and accelerator research and development efforts.

1. Development and implementation of needed maintenance and upgrades to ensure a highly reliable and enhanced operation of 3rd generation synchrotron x-ray radiation source.

2. Development, installation and maintenance of hardware and software to improve storage ring beam stability, leading to enhancing user's capability.

3. Characterize, design and develop state-of-the-art non-intercepting particle or/and photon diagnostics for the injector to enhance and optimize injector performance especially in top-up and interleave machine operating modes.

4. Development and test of innovative diagnostics and techniques applicable to existing and future light sources, to optimize the scientific and technological contribution from research at APS.

SECTOR 35: APS DIAGNOSTICS BEAMLINE

[MISSIONS]

(1) To support user operations by providing on-line information about the electron beam on a 24-hour basis (source size/center, beam divergence/direction, beam energy, and bunch length)

(2) To support machine physics studies by providing photon diagnostics on transverse and longitudinal beam properties

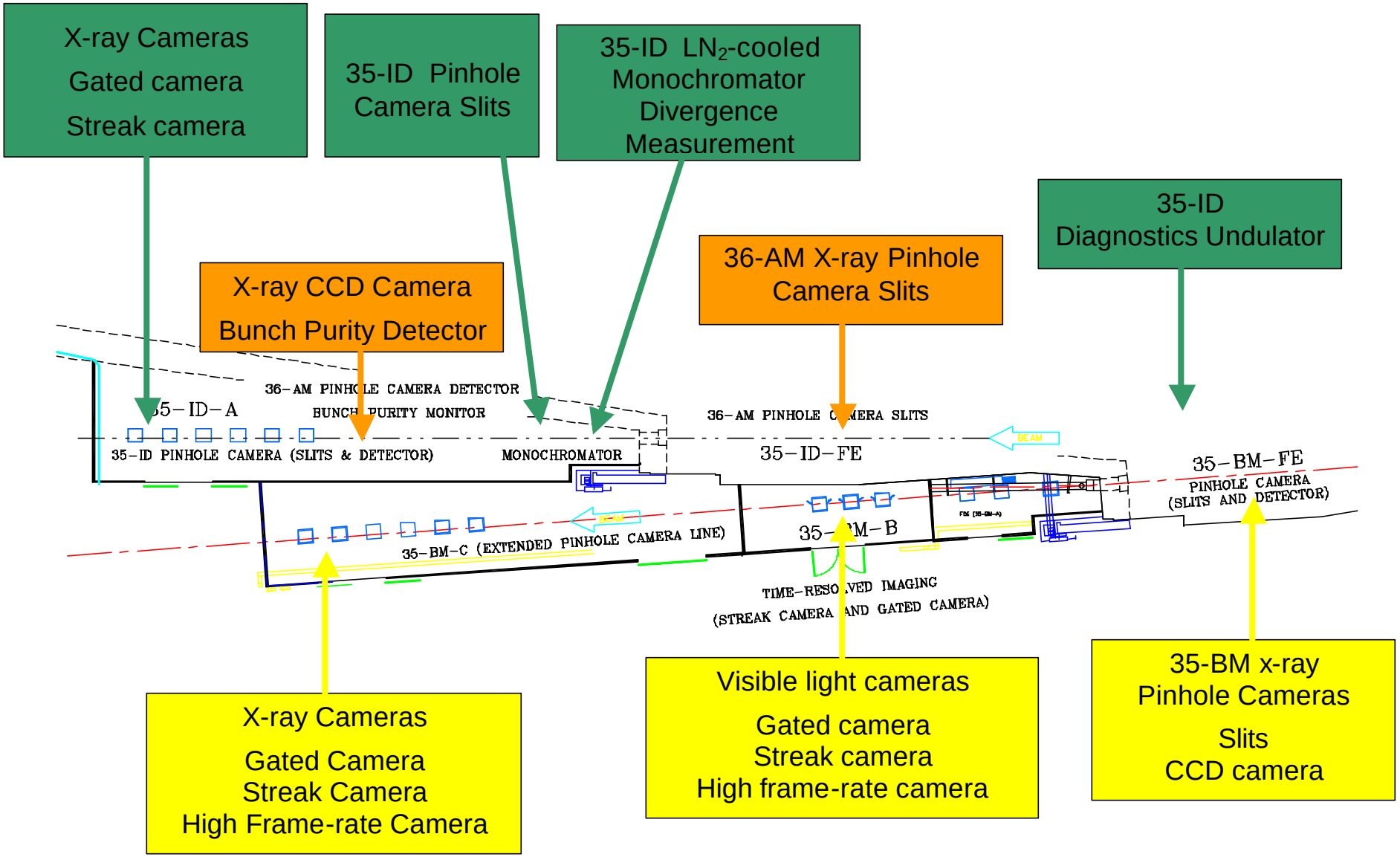
(3) To conduct research and development of diagnostics for future light sources

[STRATEGIES]

Utilize and develop time-resolved imaging with visible and x-ray synchrotron radiation to support the missions

ADVANCED PHOTON SOURCE

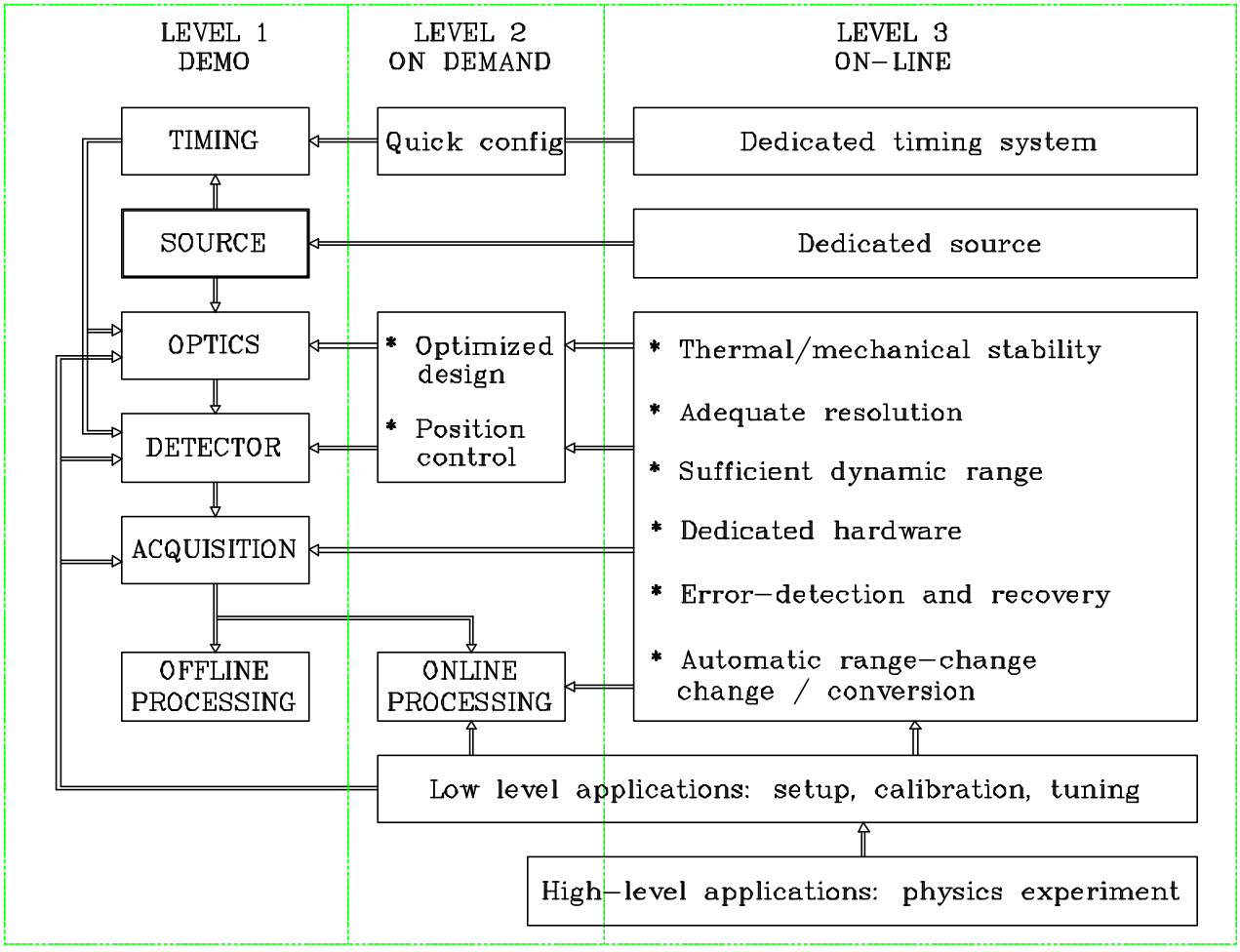
FLOOR PLAN OF SECTOR 35



Level of Development

0) Conceptual
1) One time demonstration: feasibility / adequacy
2) Available on demand: setup in several minutes to a day
3) Online and available 24 hours to operators, physicists, and data archival.

DIAGNOSTICS BEAMLINES COMPONENTS



Status of Diagnostics Beamlines

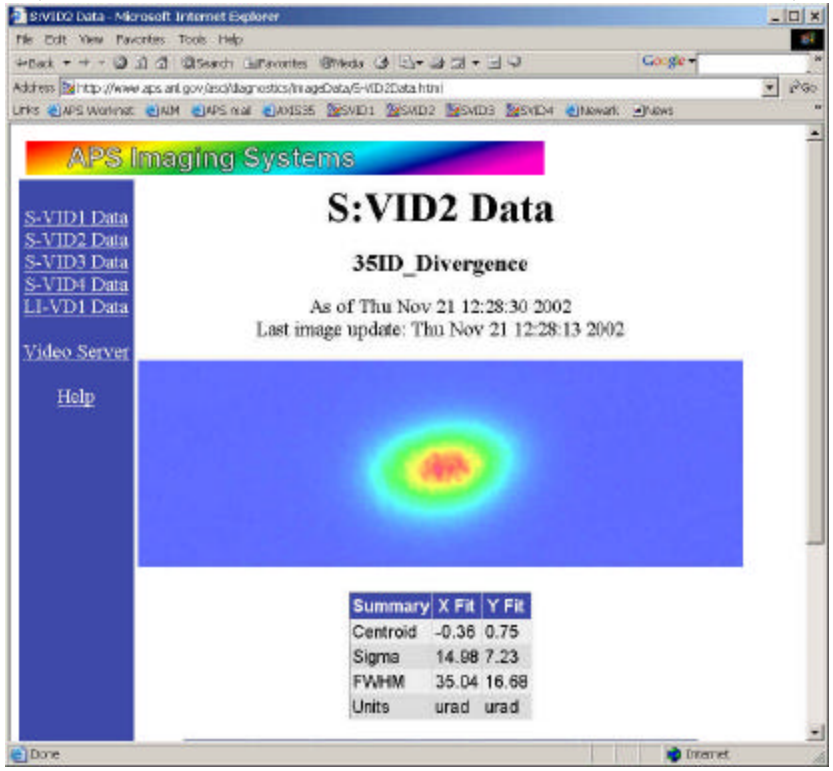
		Transverse source size and center	Beam divergence and direction	Bunch length and arrival time	*e-beam energy*	*e-beam energy spread*
BM	SLOW	Pinhole camera (online) Needs resolution improvement	N/A	OSR Streak camera on-demand	Energy measurements with AM/BM sources carry large error bars.	
	FAST	On-demand		OSR Streak camera on-demand		
AM	SLOW	Pinhole camera On-demand	N/A	Bunch purity on-demand		
	FAST	On-demand				
ID	SLOW	Pinhole camera (online) Resolution limited vertically	H_2O-cooled mono (online) Needs resolution improvement	N/A	Being developed	On-demand
	FAST	On-demand	On-demand	N/A	To be developed	

SLOW: Integration and/or repetition time > 30 ms. FAST: Integration and/or repetition time < 30 ms.

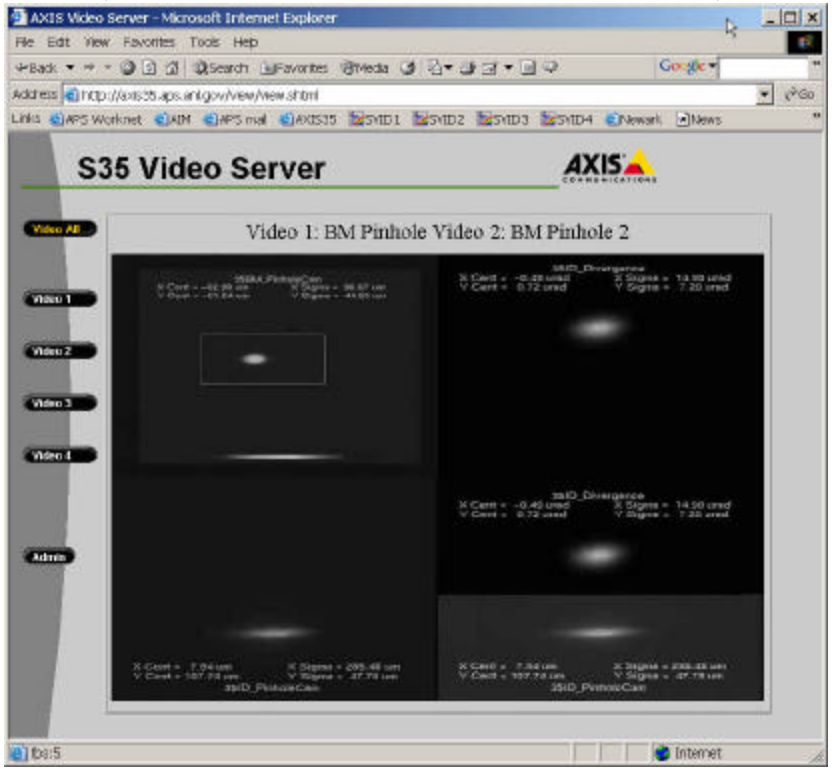
SUPPORT OF USER OPERATION:

Real-time beam image and data

(Slow web-server: ANL-wide, to be released)



(Fast web-server: APS-wide, 3/2002)



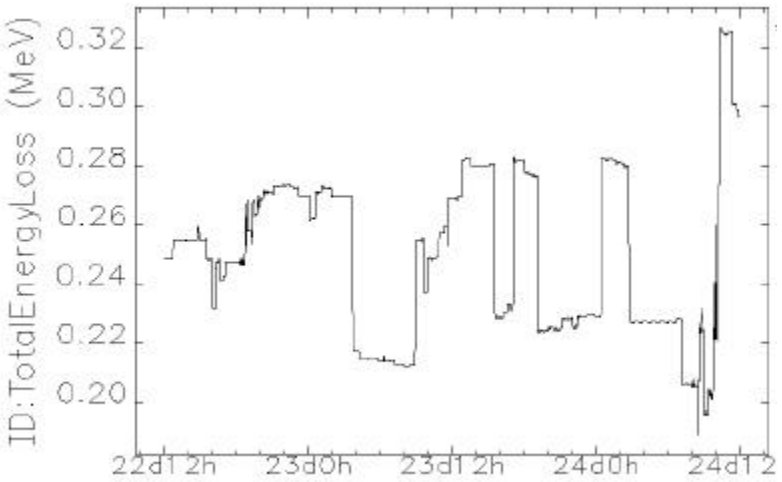
- All ID and BM images are delivered to users via APS CCTV system
- All ID and BM images are digitized to provide online beam data

SUPPORT OF USER OPERATION: Tracking beam quality

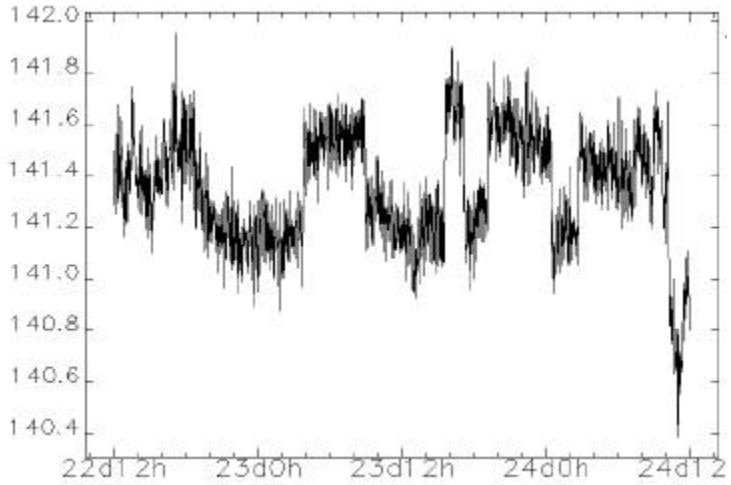
(High-emittance lattice)

Source size and divergence changes ~ 1% as a result of user ID gap changes

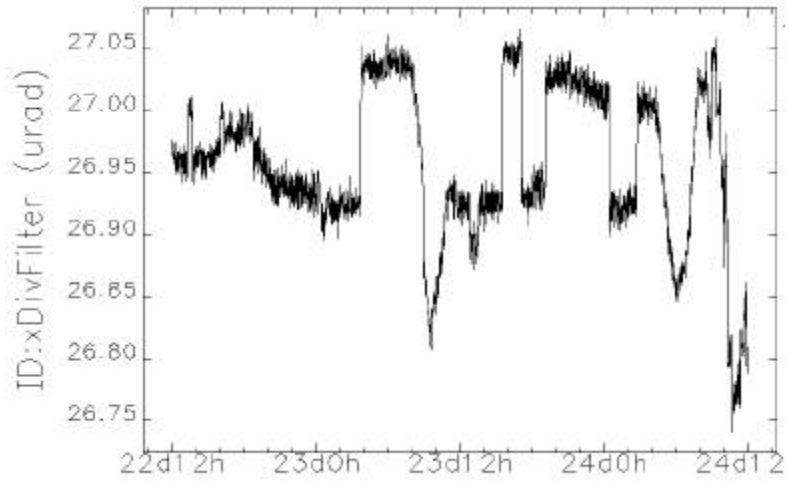
TOTAL ID ENERGY LOSS



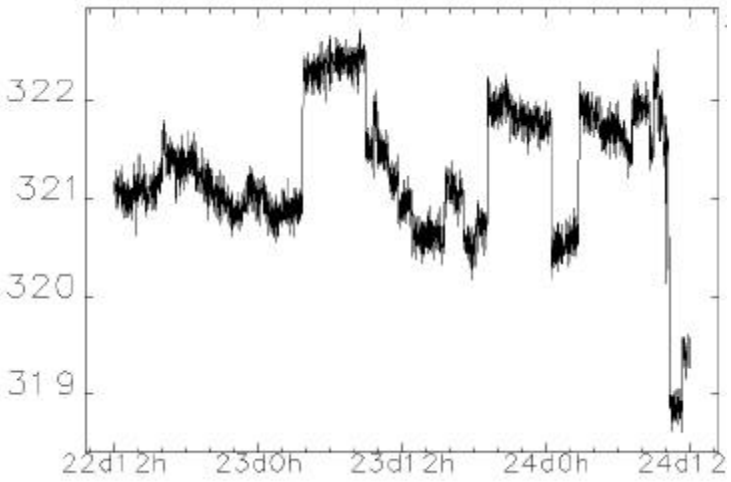
BM SOURCE SIZE (*m*m)



ID BEAM DIVERGENCE (*m*rad)

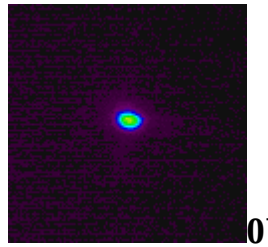


ID SOURCE SIZE (*m*m)



SUPPORT OF MACHINE STUDIES: injection transient

Gated camera single turn images (1/19/98)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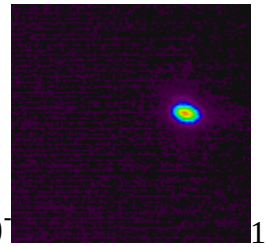
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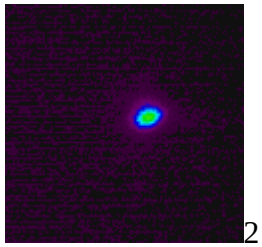
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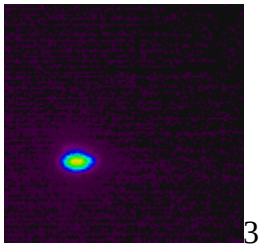
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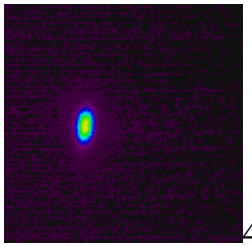
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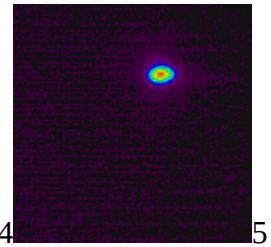
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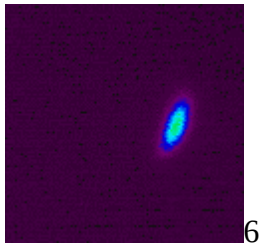
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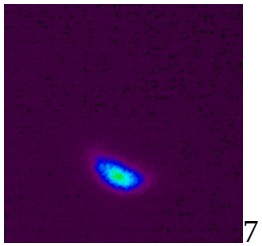
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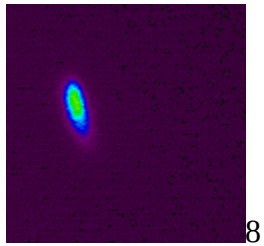
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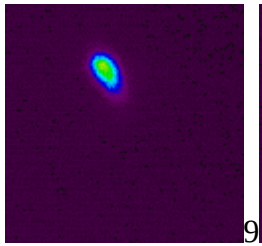
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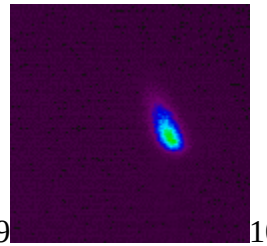
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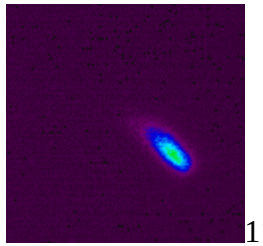
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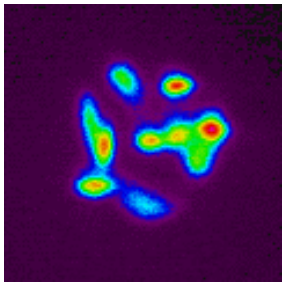
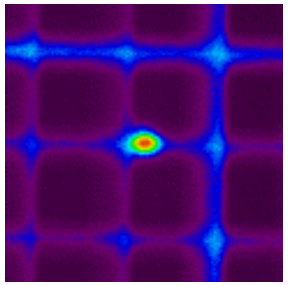
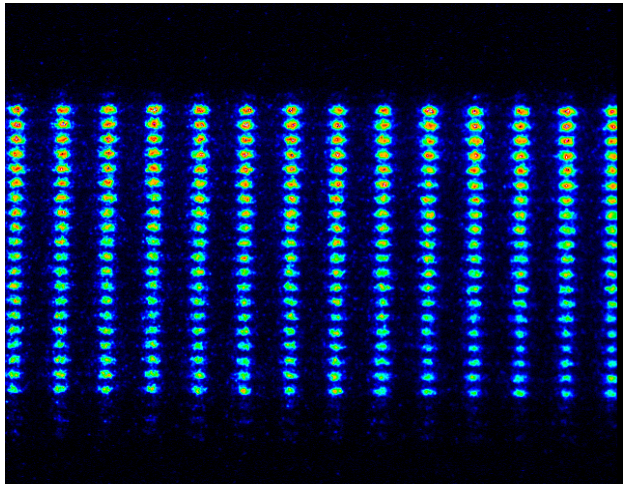

COMBINED IMAGES 0⁻→9

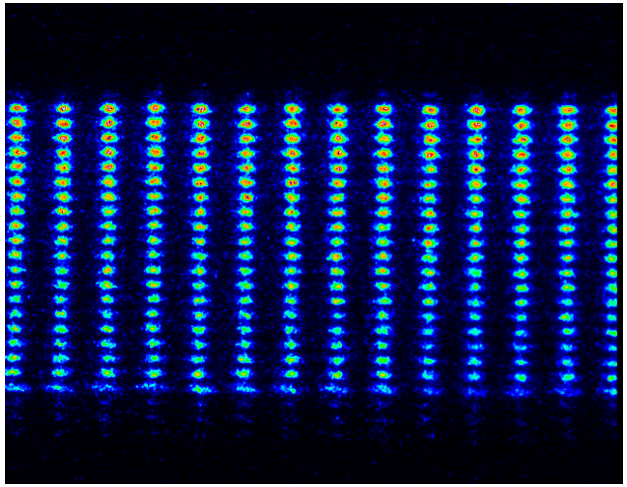

0⁻ (with 2 mm × 2mm grid)

SUPPORT MACHINE STUDIES: bunch train instability

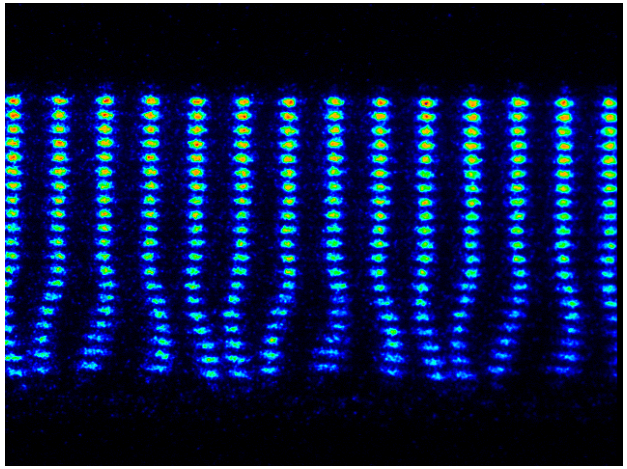
(Streak camera images, 20 mA in 20 consecutive bunches)



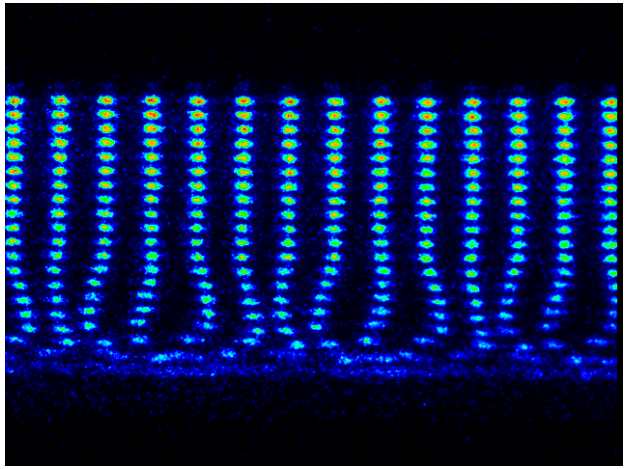
(A) $\xi=\xi_0$



(B) $\xi=\xi_0$-3.0



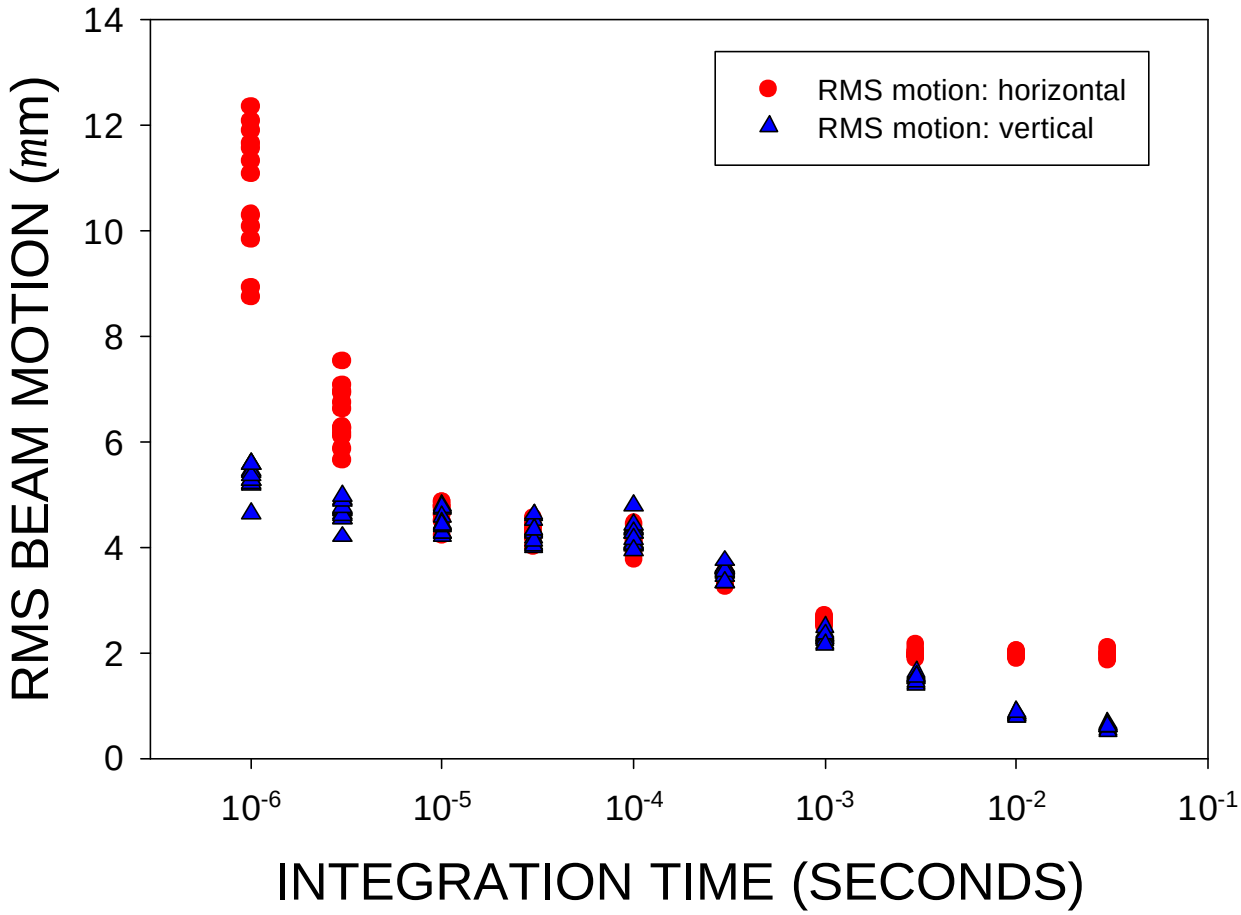
(C) $\xi=\xi_0$-4.8



(D) $\xi=\xi_0$-5.2

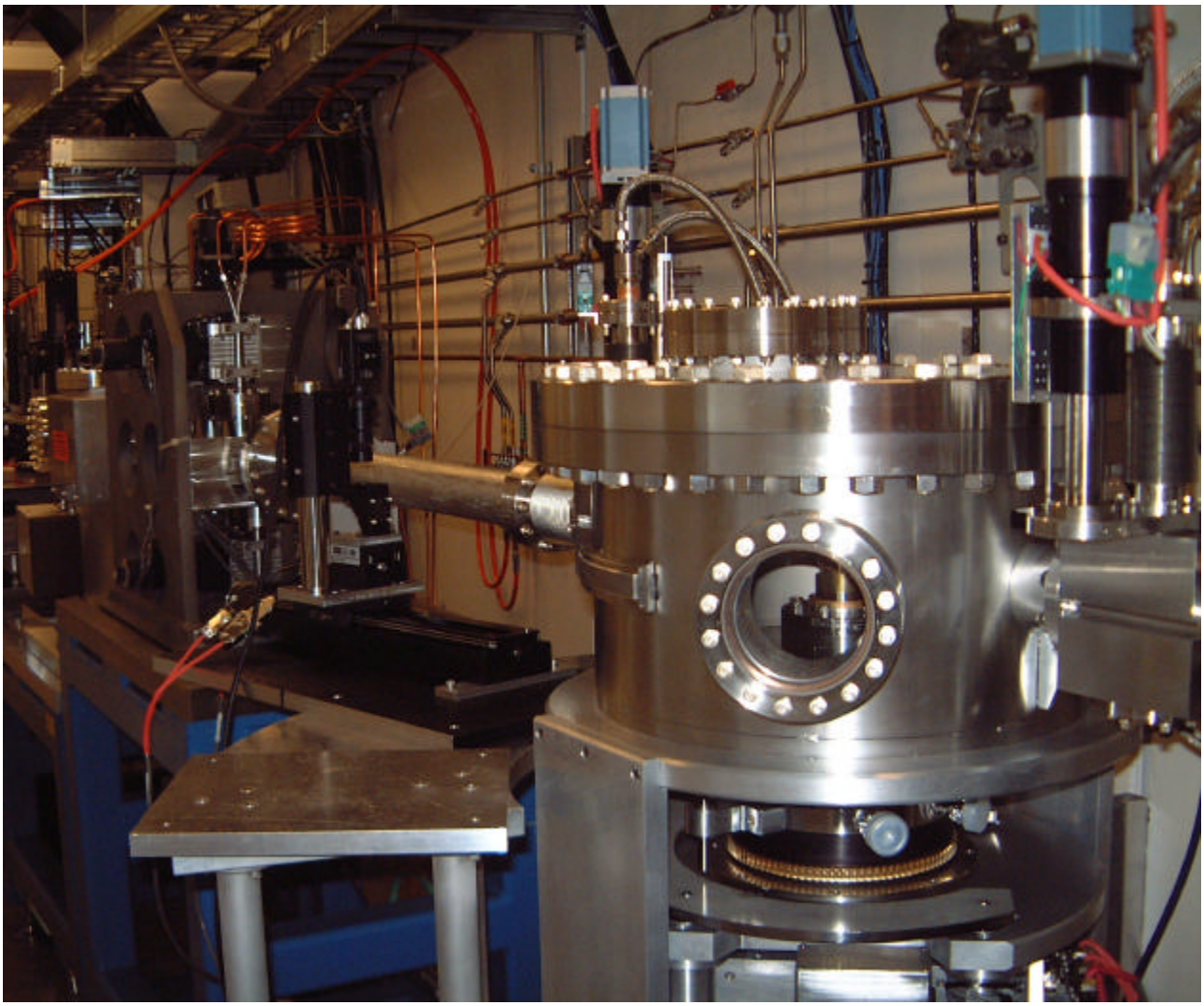
SUPPORT USER RUNS AND MACHINE STUDIES:
High frequency beam motion studies (preliminary)

(Beam motion vs. detector integration time 11/16/02)



To fully characterize the effective beam size and RMS beam motion, we need high resolution and time-resolved imaging. Ideally, we would like to communicate the results to the operators and/or users in a timely manner.

RECENT PROGRESS
Installing new 35-ID monochromator

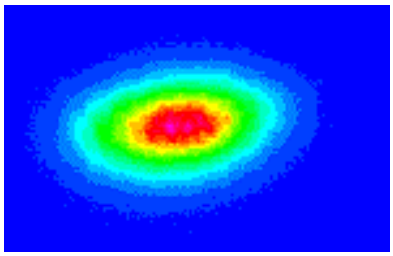


A new monochromator is being commissioned and used for providing real-time beam data.

Angular resolution:

3.0 *m*rad (water-cooled, operational)

1.7 *m*rad (LN_2-cooled, 3rd harmonic, in progress)



Time-resolved imaging (in progress)

Construction Projects in the Past Three Fiscal Years

		Transverse source size and center	Beam divergence and direction	Bunch length and arrival time	*e-beam energy*	*e-beam energy spread*
BM	SLOW	Beamline extension BLEPS; Slits upgrade Camera motorized		Streak camera automation / remote control; Phase Detector*		
	FAST	Timing system upgrade				
AM	SLOW	Camera motorized		B-Purity detector motorized		
	FAST	Timing system upgrade				
ID	SLOW	BLEPS; Camera motorized	LN_2-cooled mono* LN_2-transport / handling		x-ray energy analyzer*	On-demand
	FAST	Timing system upgrade				

SLOW: Integration and/or repetition time > 30 ms. FAST: Integration and/or repetition time < 30 ms.

* Work in progress, expect to complete in FY2003

ADVANCED PHOTON SOURCE

Proposed Projects in the Next Three Fiscal Years

		Transverse source size and center	Beam divergence and direction	Bunch length and arrival time	*e-beam energy*	*e-beam energy spread*
BM	SLOW	*4M Pinhole camera Improve resolution 22 μm → 7-10 μm		Online		
	FAST	Online fast cameras down to ~ 1 ms int. time				
AM	SLOW					
	FAST					
ID	SLOW	*X-ray imaging Improve resolution 40 μm → < 10 μm			On-demand	
	FAST	On-demand	Online fast cameras down to ~ 1 ms int. time		To be developed	

SLOW: Integration and/or repetition time > 30 ms. FAST: Integration and/or repetition time < 30 ms.
* FY2003 requests

APPENDIX: Spare Transparencies

Objectives of Diagnostics Beamlines

Primary: To measure second moments of the electron bunch

$$\sigma_x, \sigma_y, \sigma_{x'}, \sigma_{y'}, \sigma_t, \sigma_E,$$

Secondary: To measure first moments of the electron bunch

$$x_0, y_0, x'_0, y'_0, t_0, E_0$$

with adequate spatial and time resolutions.

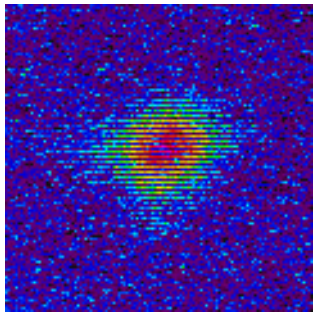
At Time Scales Relevant to Users and Machine Physics

- **SLOW: 10^{-2}—10^{6} seconds** (***Baseline***: affect most users)
- 0.1 – 1 ms (synchrotron motion, affect some users)
- 50 - 80 kHz (Betatron motion, affect some users)
- 273 kHz (revolution frequency)
- 352 MHz (RF bucket frequency)

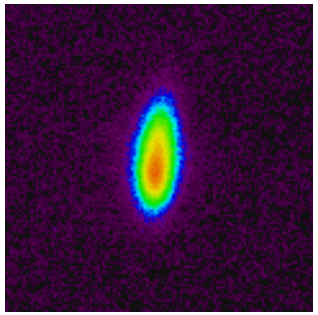
With Three Synchrotron Radiation Sources

- BM (S35 B-Magnet)
- ID (1.8 cm x 198 period Diagnostics Undulator)
- AM (S36 A-Magnet)

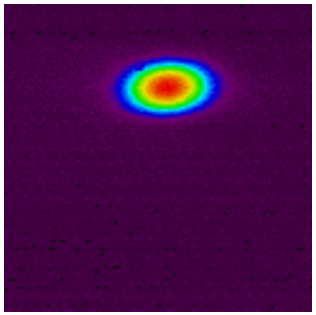
A-1 Development of BM x-ray pinhole camera



Single turn 3/18/95

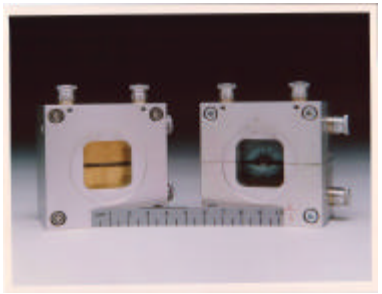


First store 4 GeV 3/25/95



First 7 GeV 6/20/95

3/1995 Optical synchrotron radiation was first used for source imaging: (s_{res}~55 mm). The resolution quickly deteriorates as current went to 100 mA.

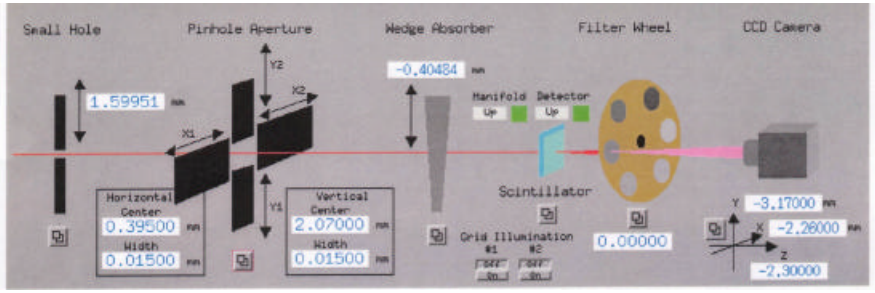


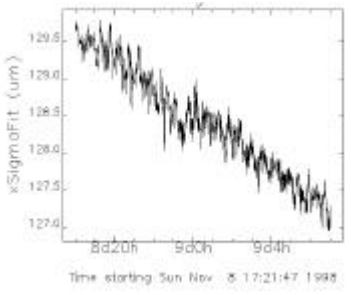
3/1996 In-air x-ray pinhole camera: (M = 0.44, s_{res} ~ 60 mm at 100 mA). Problems: pinhole corrosion.

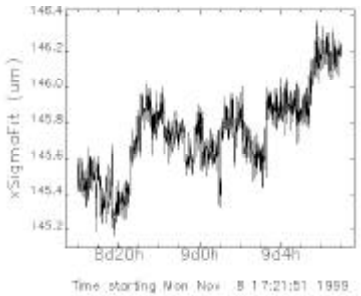
3/1997 In-vFastuum x-ray pinhole camera: (M = 0.94, s_{res} ~ 22 mm). Problems: measured beam size depends on intensity, and changes in 20 minutes cycle.

5/1998 Rewrite online data processing software in ioc S:VID1.

5/1999 Upgrade water temperature control to ±0.05°C.



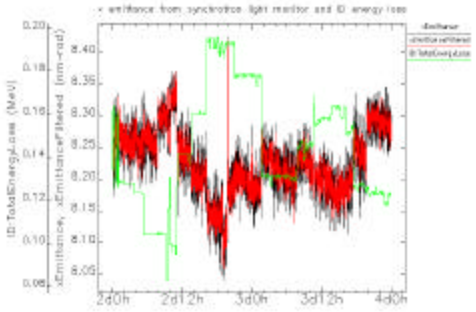


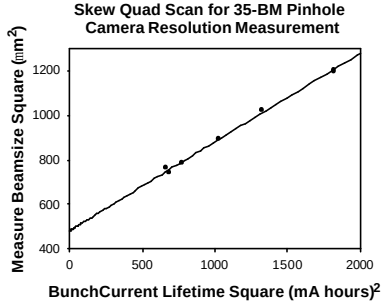


Development of BM x-ray pinhole camera (continued)

FY2000 Minor Electronics upgrade. Many of the observed beam size variations could be correlated with the user-controlled undulator gap changes.

FY2001 The pinhole camera beamline was extended to 45 m (M = 4.2). The instrument resolution was expected to be 10 — 12 μm, but we observed 18 μm! Why?





The key is the high-speed beam motion

$$\sigma_{x,Observed}^2 = \sigma_{x,Bunch}^2 + \left\langle \left[x(t) \right]^2 \right\rangle_t + \sigma_{x,Res}^2$$

$$\left\langle \left[x(t) \right]^2 \right\rangle_{Observed} = \left\langle \left\langle x(t) \right\rangle_t^2 \right\rangle$$

The observed beam size increases with integration time, while the RMS beam motion decreases, with their sum independent of the sampling time.

To fully characterize the effective beam size and RMS beam motion, we need high resolution and time-resolved imaging. Ideally, we would like to communicate the results to the users in a timely manner.

Plan of Action: (1) an adequate timing system (FY2002), a high resolution pinhole camera (M = 3 in tunnel, proposed), and high-speed detectors (proposed).

Other limitation of the pinhole camera: Limited vertical field of view. A vertical array of pinholes + intelligent data processing is one of the solutions (proposed).

A-2 Development of ID divergence and source size measurements

Undulators are the most important sources at the APS.

Beam divergence $$\sigma_{x'}^2 = \varepsilon_x \beta + (\eta' d)^2 + \frac{l}{2L} + \left\langle \left[x'(t) \right]^2 \right\rangle_t + beam\_waist\_\mathrm{mod}$$

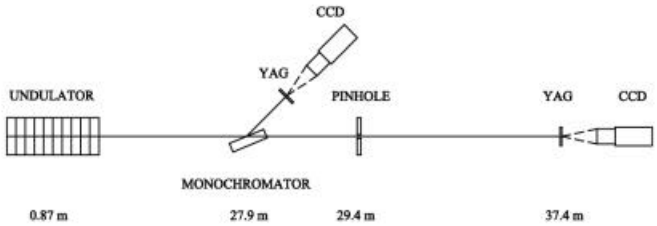
Source size $$\sigma_x^2 = \varepsilon_x \beta + (\eta d)^2 + \frac{l L}{8\pi^2} + \left\langle \left[x(t) \right]^2 \right\rangle_t + beam\_waist\_\mathrm{mod}$$

We use monochromator for measuring the divergence and pinhole camera for the size.

1992 Diagnostics Undulator concept (Decker moved RF cavity out, ¾ straight section available for ID)

FY1994 Diagnostics Undulator design / review / procurement

5/1997 First divergence measurement, He-filled single-crystal monochromator ($\sigma_{y'} = 3\,mrad$)



8/1998 ID pinhole camera measures source size

9/1998 Monochromator vacuum upgrade (24 hour service available)

1/1999 Simultaneous beam divergence and source size measurements

FY00–02 Work on LN_2-cooled single-crystal monochromator

2001 35-ID Beam divergence and source size dedicated archival

2002 35-ID beam images broadcast (CCTV and on-site web server)

10/2002 New monochromator commissioning (water-cooled)

FY2003 LN_2-cooled crystal holder designed by ASD/ME to be installed

ID divergence and source size measurements (continued)

What have we learned from the archived data:

- Centroid stability, short term and long term
- Divergence and source size stability, short term and long term
- Apparent emittance (divergence $\times$ source size) is larger than model calculations, by 8 – 12 % for high-emittance lattice, more for low-emittance lattice. However, the agreement is much better for the most recent lower-emittance lattice.

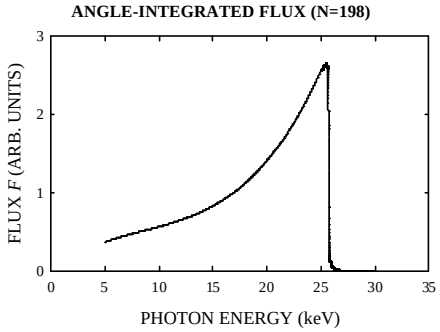
Limitations of the current setups:

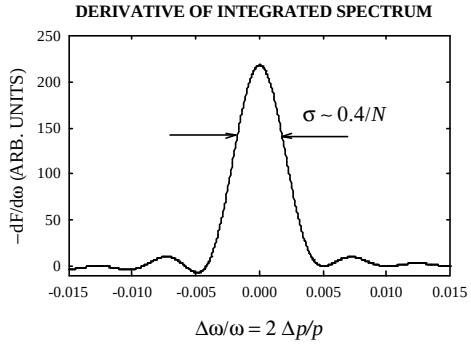
- Need to improve the vertical resolution for divergence measurements to (1.5 μrad, low coupling) ➔ LN_2-cooled monochromator crystal working at third harmonic energy (LN_2 transport / interlock funded FY01 essentially ready)
- Pinhole camera resolution limited by Fresnel diffraction to 40 μm ➔ Implement x-ray imaging device with < 200 nano-rad angular resolution (FY02-FY03, partially funded).
- A full “three screen” emittance measurement need one pinhole camera (beam waist) and two other screens, the LN_2 monochromator and an In-tunnel monochromator (proposed).

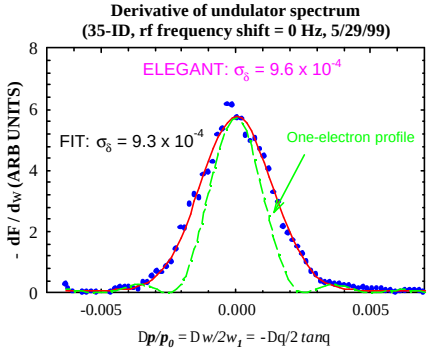
A-3 Development of undulator-based beam energy measurements

Undulators beam has rich features in its angular-spectral distribution, which carries wealth of beam information.

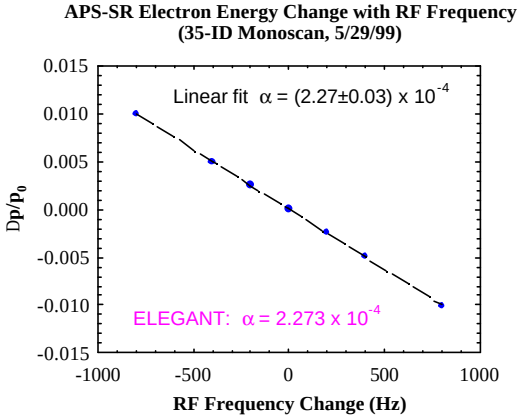
Total energy spread can be extracted from the angle-integrated spectrum.

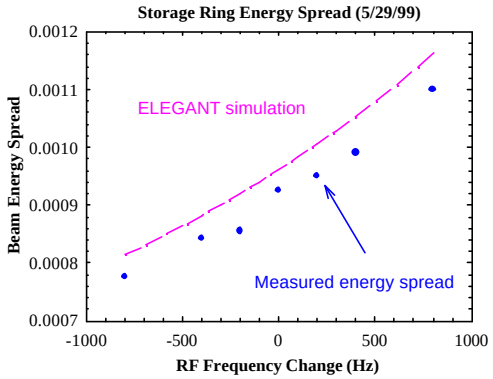


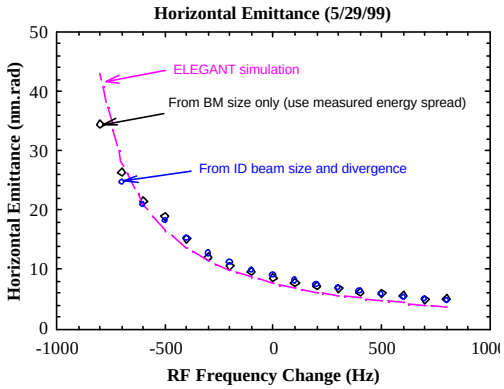




We have demonstrated that this technique is nearly independent of the beam emittance, and have used it to characterize the ring.



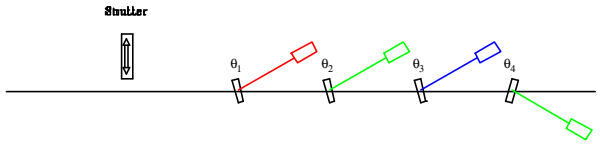




Undulator-based beam energy measurements (continued)

Absolute energy measurements (slow) are being developed. The measurements are to be based on spectral flux at positive and negative angles, as well as several crystal reflections.

A technique for FAST measurements has also been proposed. It will extract energy and direction information at the same time.



Absolute Energy Measurement (Proposed)
Measuring spectra at negative and positive angle (simultaneously) will provide a fast absolute electron beam energy measurement.